National Aeronautics and Space Administration

Cutting edge

Goddard's Emerging Technologies

Volume 12 | Issue 3 | Spring 2016

Will PIPER Find It?

www.nasa.gov

Volume 12 • Issue 3 • Spring 2016

Will PIPER Find It?

Team Set to Fly Balloon Mission Seeking Evidence of Cosmological Inflation

Now that scientists have confirmed the existence of gravitational waves, a team of Goddard scientists is set to search for a predicted signature of primordial gravitational waves that would prove the infant universe expanded far faster than the speed of light and began growing exponentially almost instantaneously after its birth.

Later this year, scientist Al Kogut and his team will fly a breakthrough balloon payload — the Primordial Inflation Polarization Explorer, or PIPER — to find evidence of this accelerated expansion, called cosmological inflation.

According to the theory, inflation would have generated gravitational waves, tiny perturbations in the fabric of space-time. These waves would have left an imprint in the polarization of the cosmic background radiation, the remnant light from the universe's creation that bathes the sky in all directions.

Scientific results from NASA's Cosmic Background Explorer and Wilkinson Microwave Anisotropy Probe (WMAP) revealed tantalizing clues that inflation did, in fact, occur. They found miniscule temperature differences in the afterglow radiation that pointed to density differences that eventually gave

Continued on page 3

in this issue:

Spring 2016

clarifications:

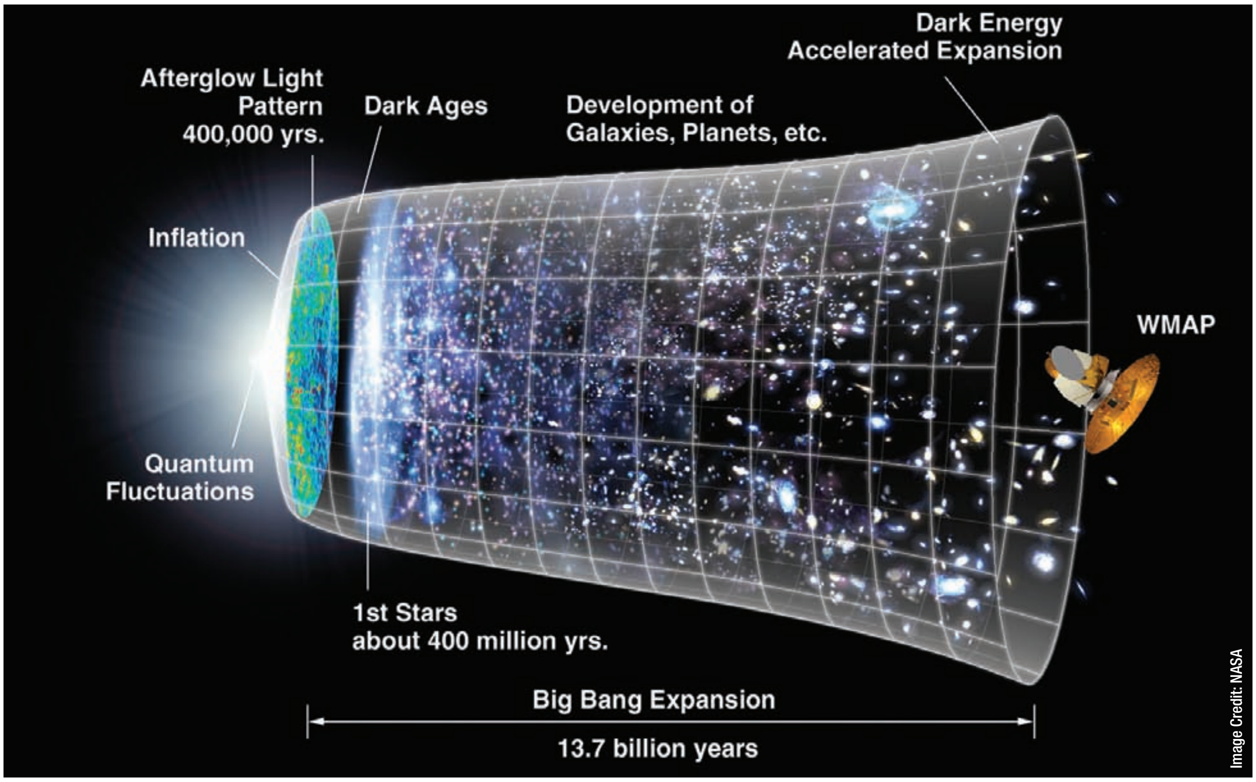
CuttingEdge wishes to clarify or correct a few items in the Winter 2016 issue. On page 15, we incorrectly reported that NASA's ICESat-2 mission will carry a 3-D printed part made of polyetherketoneketone (PEKK). The part, a bracket that supports the instrument's fiber-optic cables, is the first electrostatically dissipative Fused Deposition Modeling or strand-based 3-D printed part made of PEKK.

On page 8, CuttingEdge needs to clarify that George Washington University students designed the Goddard-provided micro-Cathode Arc Thruster system, a critical technology to be demonstrated during the CANYVAL-X CubeSat mission. In addition, we incorrectly credited a CANYVAL-X image on page 9 to KARI. Brittany Klein, a Goddard contractor, created the image. We apologize for the oversight.

About the Cover

Goddard scientist Al Kogut has spent the last several years developing a balloon-borne payload, the Primordial Inflation Polarization Explorer, or PIPER, to search for a predicted signature of primordial gravitational waves that would prove the infant universe inflated exponentially in a fraction of a second after its birth.

Photo Credit: Bill Hrybyk/NASA



This graphic shows the timeline of the universe. Although the universe has expanded gradually over most of its history, scientists believe it expanded exponentially in a fraction of a second after its birth.

rise to the stars and galaxies seen today. The observations also showed that the density differences were remarkably uniform in all directions and that the geometry of the universe was flat — physical characteristics attributable to inflation.

Although other theories also explain these dynamics, they do not explain the existence of primordial gravitational waves created when the universe inflated to astronomical dimensions. Despite repeated attempts, and at least one false alarm a couple of years ago, so far no one has discovered primordial gravitational waves or their telltale polarization signature — called B-mode, in the parlance of cosmologists.

Profound Consequences

Should PIPER find the signature proving that the universe inflated from an infinitesimally small point to macroscopic scales within a nano-nano-nano-second of the Big Bang, the discovery would have profound consequences for cosmology and high-energy physics.

While classical physics — such as Albert Einstein's general theory of relativity — works perfectly for describing gravity on the macroscopic scale (where apples fall to the ground and Earth orbits the sun), it falls apart for calculating outcomes at subatomic, or quantum, scales. In addition to establishing inflation as a physical reality, PIPER's discovery would give physicists the link between gravity and quantum mechanics.

"If we find it, it will be direct observational proof that gravity obeys quantum mechanics," Kogut said. "No one has yet worked out a consistent theory of quantum gravity; so observational evidence that gravity does obey quantum mechanics would be a huge development."

Flight Date Nears for Advanced Observatory

In June, the team plans to conduct a trial run with an engineering test unit and then follow up in September with an overnight science flight from Fort Sumner, New Mexico, to obtain a view of the Northern Hemisphere. To study the remnant light from the Southern Hemisphere, the team likely will fly PIPER from Alice Springs, Australia, in 2018.

PIPER ultimately will fly multiple times from the U.S. and Australia, soaring 120,000 feet above Earth where the atmosphere thins into the vacuum of space.

Continued on page 4

cuttingedge • goddard's emerging technologies

PIPER is a state-of-the-art, highly sensitive observatory (see related story, page 5). About the size and weight of a van, the observatory is equipped with twin telescopes, 5,120 Goddard-developed superconducting detectors tuned to far-infrared wavelength bands, and a variable-delay polarization modulator to cleanly reveal polarized light.

Because the polarization signal is at least 100 times fainter than the temperature signal detected by previous NASA missions, and even colder than the background radiation itself, PIPER must operate under super-cold temperatures to prevent instrument-generated heat from overwhelming the faint signal. As a result, the telescope, including the detectors and variable-delay polarization modulator, will be placed inside a bucket dewar filled with liquid helium to maintain a frosty -457 degrees Fahrenheit.

Difficult Measurement

Despite its unparalleled sensitivity, PIPER's mission, is a difficult one.

NASA's WMAP mission identified the E-mode signal, which exhibits a circular or radial arrangement across the sky. Its detection pointed to the time when light from the first stars ionized hydrogen atoms and liberated electrons from protons. The highly sought B-mode, on the other hand, prefers a twisty pattern. Making detection challenging is the fact that different astrophysical phenomena will produce both.

Certainly, astronomers have discovered this the hard way.

In 2014, astronomers with the Background Imaging of Cosmic Extragalactic Polarization (BICEP2) experiment at the South Pole announced that they had detected the B-mode polarization. However, their euphoria was short-lived. A thorough analysis of data collected by the South Pole's Keck Array and the European Space Agency's Planck observatory revealed that the signal came instead from dust in the Milky Way.

"BICEP2 didn't have enough information," explained Harvey Moseley, a Goddard cosmologist who has collaborated with Kogut developing technologies needed to probe the very early universe.

Although BICEP2 had observed a 400-square-degree patch of sky near the Milky Way's south pole

Continued on page 5

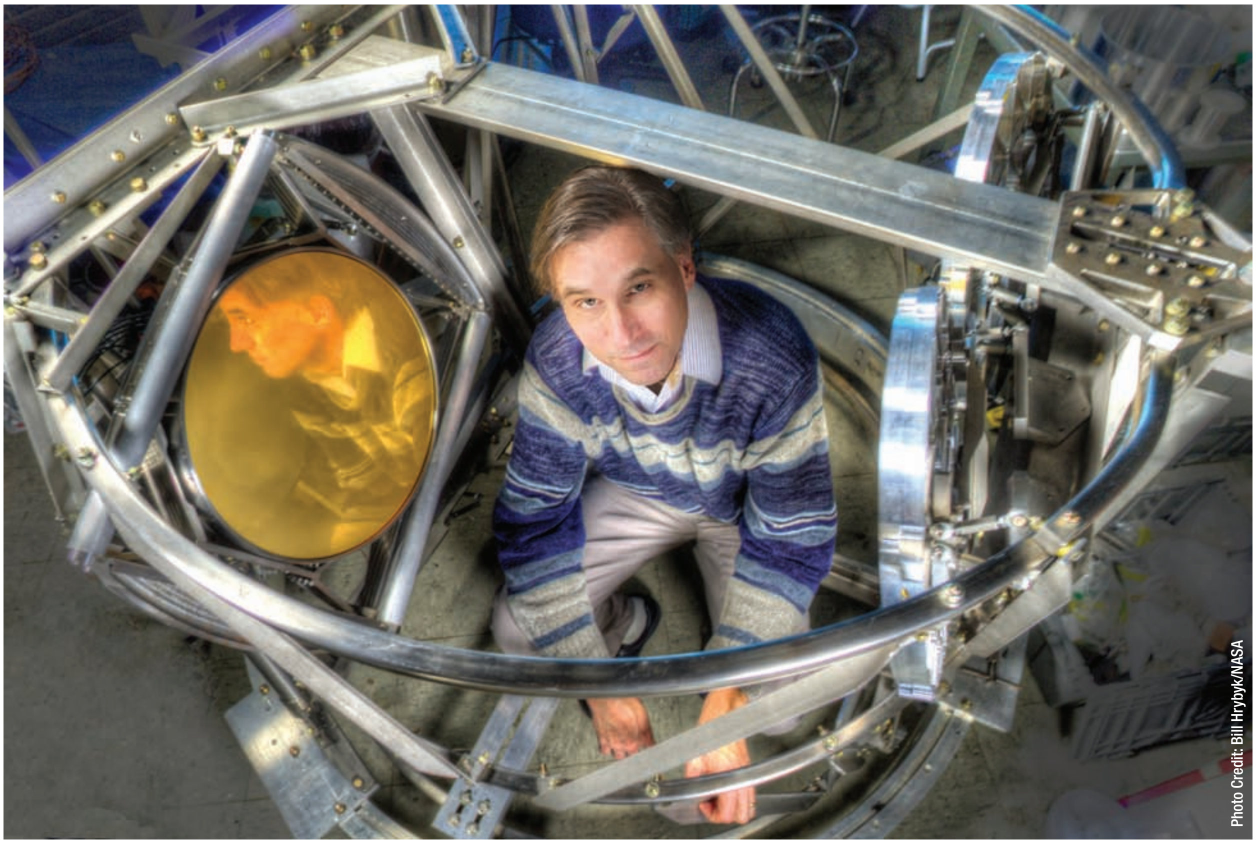


Photo Credit: Bill Hrybyk/NASA

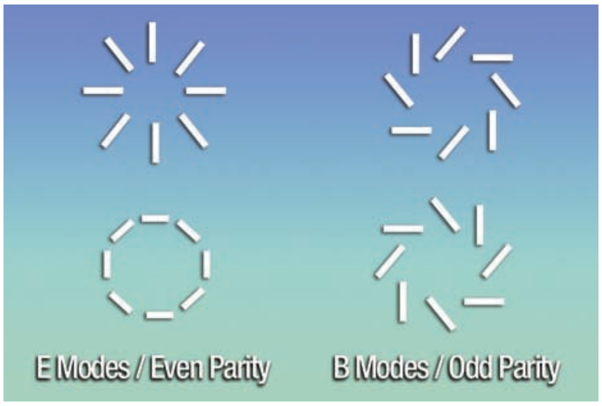
Goddard scientist Al Kogut, the principal investigator of NASA's Primordial Inflation Polarization Explorer, is shown here with structural components of the balloon payload slated for a test run in June. The first of several science flights is set for this fall.

— a region free of much of the dust that fills the star-studded disk — the telescope looked at only one frequency range. The team tuned the instrument to 150 GHz, which is favorable for studies of the background radiation. To be truly cosmological in nature, however, the measurement should have been crosschecked at multiple frequencies.

In sharp contrast, PIPER will observe the whole sky at four different frequencies — 200, 270, 350, and 600 GHz — to discriminate between dust and primordial inflation, Kogut said. This assures that the team will be able to remove the dust signal. Furthermore, PIPER will fly aboard a high-altitude scientific balloon to avoid emissions from Earth's atmosphere. If the gravitational waves exist, PIPER will detect their signature to a factor of three fainter than the lowest value predicted by inflationary models, Kogut said. In addition, the telescope will carry out its task 100 times faster than any ground-based observatory.

Good News, Either Way

Even if PIPER fails to detect the signature, the scientific community still would herald the mission a success. "It will be a big deal if they find the signal, but it also will be a big deal if PIPER can't see it," Moseley said. "It means that we need to come up with a different model of what happened in the early universe." ❖



Previous NASA missions identified E-mode polarization in the cosmic microwave background, the remnant light from the universe's creation. The E-mode signal stems from a later period, when ultraviolet starlight began stripping electrons from hydrogen atoms, ionizing them. PIPER is seeking evidence of primordial gravitational waves and their telltale polarization signal — B-mode.

CONTACT

Alan.J.Kogut@nasa.gov or 301.286.0853

PIPER to Showcase Pioneering, Goddard-Developed Technologies

If scientists prove or even disprove the theory of cosmological inflation with the Primordial Inflation Polarization Explorer, or PIPER (see related story, page 2), kudos will go at least in part to three pioneering Goddard-developed technologies.

Together, they will help the observatory achieve an order-of-magnitude improvement in sensitivity compared with current polarization experiments.

Detector Arrays

Chief among the technologies are the mission's advanced bolometer detectors, which Goddard technologist Christine Jhabvala first demonstrated nine years ago on a ground-based, 30-meter observatory in Spain (*Goddard Tech Trends*, Spring 2008, Page 5). Since their debut, the detector arrays have evolved. They are larger, providing more pixels with which to measure the faint background radiation, and they are far more sensitive.

Continued on page 6

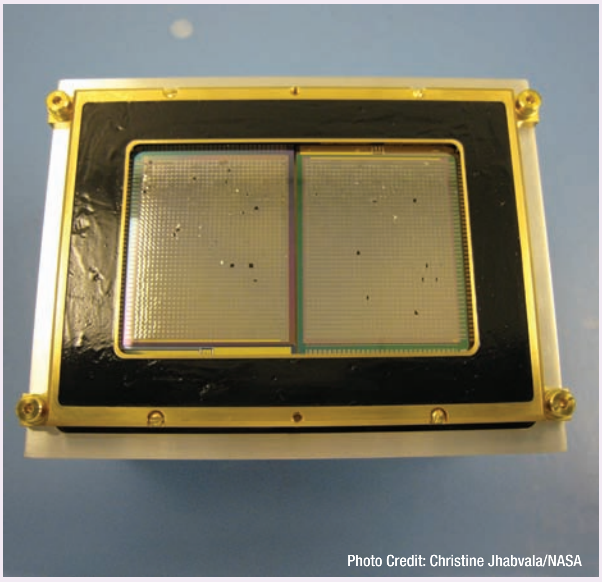


Photo Credit: Christine Jhabvala/NASA

This kilopixel detector array developed by Goddard technologist Christine Jhabvala is similar to the four arrays flying on PIPER. Each array contains 1,280 pixels, each about one-milimeter square, composed of a membrane of silicon one micrometer in thickness.

Bolometers are commonly used to measure infrared or heat radiation, and are, in essence, very sensitive thermometers. When radiation strikes an absorptive element, typically a material with a resistive coating, the element heats. A superconducting sensor then measures the resulting change in temperature, revealing insights into the physical properties of the distant object being studied.

PIPER will fly four separate 1,280-pixel bolometer arrays based on the backshort under grid, or BUG, architecture that Jhabvala and her team pioneered. The technique places reflective optical structures, called backshorts, one-quarter of a wavelength of light behind each pixel in the bolometer plane. The backshort stops the light and reflects it back into the absorber, thereby increasing detector sensitivity.

"These detectors could sit at Goddard and easily spot a 60-watt light bulb in California," Jhabvala said.

Photo Credit: Bill Hrybyk/NASA

Paul Mirel, a Goddard contractor, created the variable-delay polarization modulator that will separate polarized from non-polarized light during the upcoming PIPER balloon mission. The device is a grid made of closely placed copper-plated tungsten wires and a mirror situated behind the grid.

Modulator and Dewar

Before the detectors receive the light for analysis, the incoming radiation must first enter an open aperture, where it meets the variable-delay polarization modulator made of a grid of closely placed copper-plated tungsten wires and a mirror situated behind the grid. Built by PIPER Chief Engineer Paul Mirel, the modulator ensures that only polarized light reaches PIPER's optics. From the optics, the modulated light travels to the four identical BUG arrays.

Because instrument-generated heat could easily overwhelm the signal PIPER seeks, the detectors are cooled with a device called an adiabatic demagnetization refrigerator — another Goddard-developed technology. The entire payload, including the modulator, optics, and BUG detector arrays, is inserted inside a large bucket dewar containing superfluid liquid helium.

"By combining proven technologies, I believe we have created an observatory that will give us an unprecedented level of sensitivity at a very low technological risk," said PIPER Principal Investigator Al Kogut. ❖

CONTACTS

Christine.A.Jhabvala@nasa.gov or 301.286.8694
Paul.Mirel@nasa.gov or 301.286.5467

PROFILE

CuttingEdge occasionally publishes profiles about Goddard scientists and engineers who distinguish themselves on the job as well as off. Here, we profile Paul Mirel, a Goddard contractor employed by Wyle Science, Technology and Engineering Group, who exercises his engineering creativity at an institution not even remotely related to spaceflight.

Left Brain, Meet Right Brain

Creator of Enabling NASA Technology Moonlights at Maryland Art School

It all started because Paul Mirel, who created an important enabling technology for the Goddard-developed Primordial Inflation Polarization Explorer (see related story, page 5), wanted to give his then three-year-old niece a birthday gift she would never forget.

This "princess" dress, which engineer Paul Mirel designed for his niece, led to his unique collaboration with a Baltimore-based art school.

While she loved coloring books, she also had an affinity for princesses; so Mirel set out to create a dress that would befit royalty, equipping it with tiny light-emitting diode bulbs that would change patterns and colors depending on how his niece moved. "A friend said, 'you have to talk with an Annet Couwenberg. She will love what you're doing,'" Mirel recalled, referring to one of the instructors at the Baltimore-based Maryland Institute College of Art (MICA) who teaches a fiber and technology class.

Mirel contacted the instructor, thinking he might be able to help the institute's various departments. The school took him up on his offer.

His overture has since evolved into a paid position. For the first year, he volunteered at MICA's Digital Fabrication Studio, a state-of-the-art facility that houses 3-D printers and other equipment that students use to model and create everything from violin bows, microfibers, to actual objects of art. Now, he works as a visiting engineer for the Graduate Studies Department and teaches workshops on mechanism design for a toy design class and electronics for an interactive animation class.

"Paul's skills are so valuable," said Ryan Hoover, an artist and instructor at the Digital Fabrication Studio. "Artists sometimes don't approach things in an efficient way. If we want artists to interpret the world, they need a strong understanding of technology and how it is shaping our world. Paul is providing that for us."

From his evening and weekend moonlighting job, which he sees as a hobby, Mirel said he's gained as much as he's given. "One student built a 3-D printer from scratch," Mirel said. "They don't know what they 'can't' do, so they just jump in and see what happens."

He's convinced NASA engineers in general and NASA in particular could benefit from how art students think.

Although the students' backgrounds in sculpture and artistic design would appear to be light-years away from the by-the-numbers perspective of many engineers, the two face the same electronic, mechanical, materials, and software challenges — at least at MICA's Fabrication Design Studio, which is unique in offering its students an opportunity to experiment with 3-D printers and other technology as part of their instruction. The difference is in how they approach their challenges, Mirel said.

"I'm trying to make a connection between the art school and Goddard. I'm encouraging the students to apply for internships. I believe we all would benefit from a transfer of expertise in both directions," he said.

As for his niece's gift, Mirel said he gave the dress to her on her fifth birthday and she loves it. ❖

CONTACT

Paul.Mirel@nasa.gov or 301.286.5467

Volume 12 • Issue 3 • Spring 2016

Shake, Rattle, and Roll

Modeling and Simulation Capability Developed to Measure Impact of Earthquakes on Earth's Gravitational Field

A Goddard team has developed a sophisticated modeling and simulation capability to help measure gravity changes that occur when magnitude-8 and larger earthquakes and subsequent tsunamis shake the planet.


Photo Credit: Chris Chapman, Schlumberger Cambridge Research, Cambridge, United Kingdom

The 9.1-magnitude earthquake that occurred off the coast of Sumatra, Indonesia, in 2004 generated a tsunami that devastated the Indian Ocean region. A Goddard team modeled and simulated this event to demonstrate a new technology that reveals more about the impact of earthquakes on Earth's gravitational field.

The capability is now being used by scientists analyzing data collected by the twin satellites that make up NASA's Gravity Recovery and Climate Experiment, or GRACE, as well as by those now planning the GRACE Follow-on, a similarly outfitted successor that NASA expects to launch in 2017.

Since its launch in 2002, GRACE has gathered detailed measurements of Earth's changing gravitational field. The two identically equipped spacecraft fly in formation about 137 miles apart in a polar orbit 310 miles above Earth.

The pair maps Earth's gravitational field by measuring the distance between the two satellites, using GPS and a microwave-ranging system. As the lead satellite approaches a region of greater gravity, it's pulled a little farther ahead of the trailing satellite, slightly increasing the distance between them. As the lead satellite flies past, it gets pulled slightly back while the trailing satellite, which is now approaching the gravitational mass, is pulled slightly ahead.

As a result, GRACE'S maps, which the mission produces every 30 days, not only show how the planet's gravity differs from one location to another, but also over one period of time to another.

These gravitational differences happen because of a variety of reasons, the most significant being the movement of Earth's water, both in liquid and ice forms. These changes can reveal much about sea-level rise, polar ice-cap loss, runoff, and groundwater storage on land masses — conditions of interest to climatologists.

Impact of Earthquakes

However, earthquakes also affect Earth's gravitational field, the invisible force that keeps the planet's atmosphere and inhabitants from flying off into space.

"What we set out to do was determine how big the signal should be, what we would see in the data," said Goddard technologist Jeanne Sauber, who collaborated with former Goddard scientist Shin-Chan Han, now a researcher at Newcastle University in Australia, to develop the sophisticated modeling and simulation algorithm.

To test the technology, the team modeled and simulated the so-called "Boxing Day" earthquake and tsunami that occurred on Dec. 26, 2004, when the Burma tectonic plate moved sideways and below the Indian plate, triggering a 9.1-magnitude earthquake and a series of tsunamis that ultimately killed 227,898 people living along the coasts of most countries bordering the Indian Ocean.

The event, which began off the west coast of Sumatra, Indonesia, was so powerful that it caused the entire planet to vibrate by as much as a centimeter, triggering earthquakes as far away as Alaska. After events such as this one, "Earth actually rings for a week," Sauber said.

Continued on page 9

To carry out the demonstration, Sauber tapped the simulation capabilities offered by Goddard's Laboratory for Planetary Geodynamics — in particular, the lab's GEODYN software. The software is used to determine orbits and estimate geophysical parameters, Sauber said.

"They gave me their equations for gravitational perturbations caused by a massive earthquake," recalled David Rowlands, a space geodesist at the lab. "We have actual observations from tracking stations and satellites from around the time of the earthquake. We put all this into our software to see if the observations agreed with the simulations."

They did. "What was novel was the transient or short-term reverberations," Sauber said.

Among other things, the GRACE mission now is using the simulation capability to remove earthquake-related perturbations in the satellite measurements, assuring that changes are not incorrectly attributed to the melt-off of polar ice sheets or another climate change-related phenomena.

Capability Does More

However, the simulation capability will do more. Even next-generation gravity missions, such as the conceptual GRACE-2, would likely benefit from the capability, Sauber said. Currently, her colleague, Goddard scientist Scott Luthcke, is investigating the use of an emerging technology called atom interferometry to measure gravity changes with even greater precision (*CuttingEdge*, Fall 2013, Page 6).

Atom interferometry works much like optical interferometry, but at quantum or sub-atomic scales. Under completely different physical processes, both split light spatially and then recombine the light to create an interference pattern that provides highly precise distance measurements.

"The only way we can know the benefit of new technologies is to run simulations," Sauber said, adding that the ultimate goal with next-generation gravitational-field measurements is identifying the effect of a less-powerful earthquake — a 7.5-magnitude event, for example. "A next-generation instrument might even be able to see Earth moving silently at a particular depth," possibly portending the onset of an earthquake, she added. ❖

CONTACT

Jeanne.M.Sauber-Rosenberg@nasa.gov or 301.614.6465

Something Old Becomes New

Goddard Team Repurposes Passive Thermal-Control Technology for CubeSats

An older technology once de rigueur for preventing spacecraft gadgetry from getting too hot or too cold has been resurrected and repurposed for an emerging class of small satellites now playing an increasingly larger role in space exploration, technology demonstration, and scientific research.

Goddard Principal Investigator Allison Evans and her team, including technologists Cindy Goode and Todd Bentley, have successfully miniaturized the thermal-control technology and now plan to test it on the maiden flight of the Goddard-developed Dellingr spacecraft. Engineers created this new-fangled 6U CubeSat to accommodate NASA-class scientific investigations at a lower cost (*CuttingEdge*, Fall 2014, Page 4). The tiny Dellingr measures about 12 inches long and four inches high, and could launch later this year, developers said.

"CubeSats were traditionally used by the university research community," Evans said. "They ran on only a few watts of power, carried very small

Continued on page 10

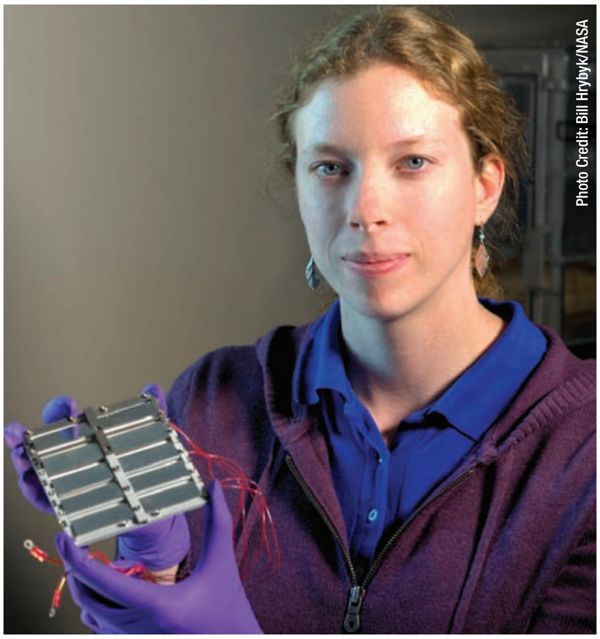


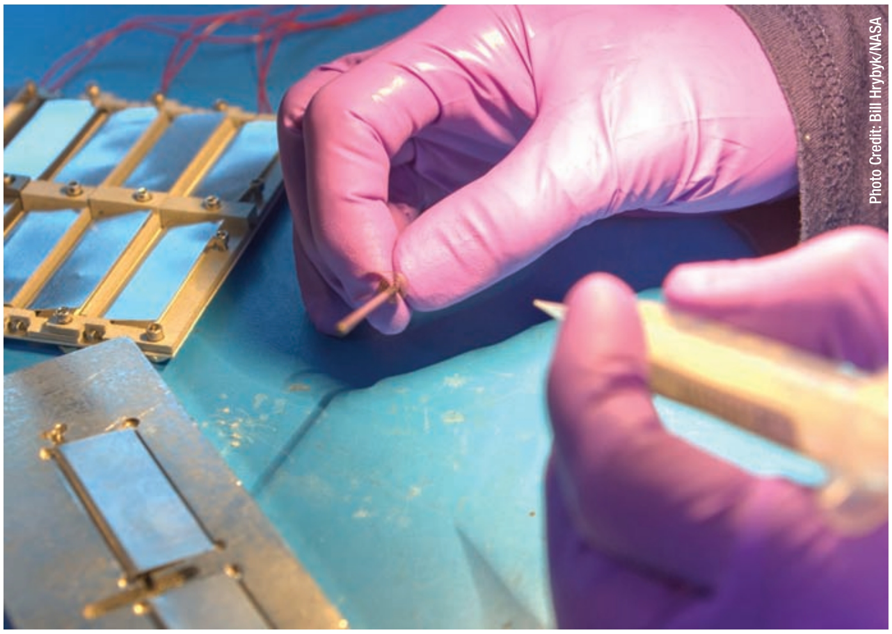
Photo Credit: Bill Hrybyk/NASA

Principal Investigator Allison Evans has repurposed an old thermal-control technology specifically for the increasingly popular CubeSat platform.

payloads, and had mission lifetimes of only a few hours to weeks in low-Earth orbit. However, this paradigm is changing."

Given its relatively low cost and fast turn-around time, NASA and others are adopting the CubeSat platform for a range of multi-year exploration, technology-demonstration, and scientific missions.

Some deployable solar panels designed specifically for this spacecraft class now can provide 80 watts of peak power, enabling more power-intensive CubeSat missions.



Technologist Cindy Goode holds the tiny spring essential to operating the new thermal-control device that will be demonstrated during Goddard's 6U Dellingr mission.

Overcoming Thermal-Control Challenges

The higher wattage has created challenges, however. How do mission designers regulate the temperature of the more power-hungry or temperature-sensitive flight instruments inside satellite buses that can be as small or smaller than a cereal box? Electronic thermal-control devices add weight and consume valuable space, making them less appropriate for small satellites, she said.

"One of the things I observed at the time was that no one had begun developing passive thermal-control technology for CubeSats," Evans said.

She embraced the challenge, turning to a technology used initially in the 1960s — a large panel of louvers measuring a couple feet in diameter. Like venetian blinds, the louvered flaps would open or close depending on whether an instrument needed to shed or conserve heat. The new thermal-control louver technology operates in much the same way as its forebear. It, too, requires no electronics and is completely passive.

The device measures about four inches on a side, about the size of a 1U cube face, and can be linked together to accommodate almost any small-satellite mission, whether it is a 3U CubeSat or something larger than even Dellingr. Each unit includes front and back plates, flaps, and springs. The back plate is painted with a white, highly emissive paint — boron nitride nano mesh (BNNM) — developed by Goddard materials expert Mark Hasegawa. The front plate and flaps are made of aluminum, which aren't as emissive.

"The bimetallic springs do the heavy lifting," Evans said. Measuring just a quarter-of-an-inch in diameter, the springs are made of two different types of metal. Attached to the highly emissive back plate, they uncurl if one of the metals gets too hot, forcing the flaps to open. When the spring cools down, it reverts back to its original shape and the flaps close.

Testing Proves Effectiveness

Since building the device, Evans and her team have put the unit through the paces to determine performance.

In a benchtop lifecycle test, the team ran more than 12,900 cycles exposing the device to temperatures of between 91 to 131 degrees Fahrenheit. The bimetallic springs experienced no failures, she said. The team also carried out eight thermal-vacuum test cycles at temperatures of between -4 degrees and 185 degrees Fahrenheit, finding that the technology dissipated an amount of thermal energy significant to a CubeSat. A vibration test also indicated the technology had achieved qualification levels.

The proof of its effectiveness, however, will come during the Dellingr mission, she said. During that technology demonstration involving a smaller experimental version, she is anticipating that the device will prove its effectiveness as a spaceflight technology. ❖

CONTACT

Allison.Evans@nasa.gov or 301.286.6194

3-D Printing Investigated for Building Densely Populated Electronic Assemblies

As detector assemblies get smaller and denser — packed with electronic components that all must be electrically connected to sense and read out signals — it's becoming increasingly more challenging building these all-important instrument devices.

A team of Goddard technologists, however, has begun investigating the use of a technique called aerosol jet printing to produce new detector assemblies not possible with traditional processes.

"If we succeed, aerosol jet technology could define a whole new way to create dense electronic board assemblies and potentially improve the performance and consistency of electronic assemblies," explained technologist Beth Paquette, who is leading the R&D effort that began last fiscal year. Furthermore, aerosol jet printing promises to slash the time it takes to manufacture circuit boards, from a month to a day or two, she added.

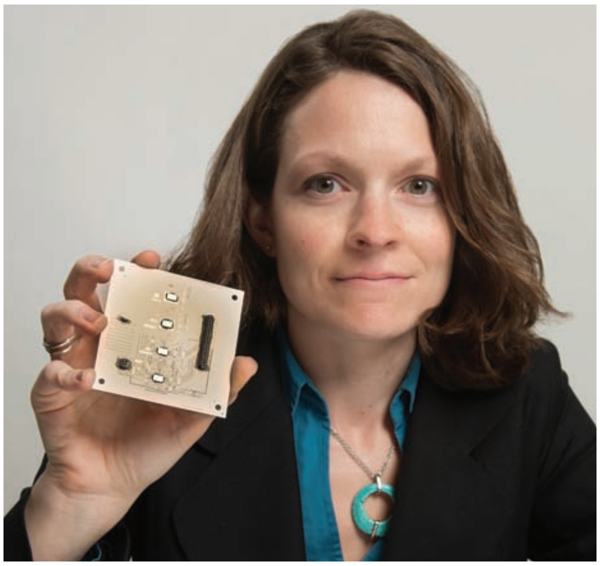
As with other 3-D printing techniques, aerosol jet manufacturing builds components by depositing materials layer-by-layer following a computer-aided design, or CAD, drawing. However, jet aerosol printing offers an important difference.

Instead of melting and fusing plastic powder or some other material in precise locations, as in the case of many 3-D printers, aerosol jet printing uses a carrier gas and printer heads to deposit a fine aerosol of metal particles, including silver, gold, platinum, or aluminum, onto a surface. Aerosol jet printers also can deposit polymers or other insulators and can even print carbon nanotubes, cylindrically shaped carbon molecules that have novel properties useful in electronics and optics.

"It can print around bends, on spheres or on something flat, or on a flexible surface, which then can be flexed into the shape you want," she said.

These attributes make the technology ideal for detector assemblies, particularly those that need to be shaped differently or are very small, yet dense because of the large number of tiny components that must be electrically wired or linked together on a circuit board — an inescapable reality as instruments get smaller and smaller.

"We can make these wires microns in width," Paquette said. "These lines are very small, down to 10 microns wide. These sizes aren't possible using traditional circuit board manufacturing processes." (By way of comparison, the average human hair measures between 17 and 191 microns in width, depending on type.)



Goddard technologist Beth Paquette holds a small ceramic board with four radiation-hardened digital-to-analog converter chips (in the middle of the board). She created the circuitry using a 3-D printing technique.

However, the technique's use isn't limited to detector electronics. Goddard technologist Wes Powell, the assistant chief for technology in Goddard's Electrical Engineering Division, envisions a time where instrument developers could use aerosol jet technology to print antennas, wiring harnesses, and other hardware directly onto a spacecraft.

Paquette's research involves NASA's Marshall Space Flight Center, the National Institute of Standards and Technology, the University of Maryland's Laboratory for Physical Sciences, the University of Delaware, Georgia Tech, and the University of Massachusetts-Lowell. In addition, several industry groups are involved.

The team now is evaluating the technique's repeatability and robustness, particularly for a spaceflight application. "Aerosol jet printing has the potential for many configurations, but the deposits have not yet been assessed under typical flight conditions. That's what we're doing here," she said. ❖

CONTACT

Beth.M.Paquette@nasa.gov or 301.286.8647

Volume 12 • Issue 3 • Spring 2016

Goddard Team Competes for New SOFIA Opportunity

Main Photo: Goddard scientist Harvey Moseley and his team are fine-tuning an instrument concept, which, if selected by NASA this fall, would carry out its science mission from NASA's Stratospheric Observatory for Infrared Astronomy, or SOFIA. Inset Photo: This Hubble Space Telescope photo is the most detailed picture to date of a large, edge-on, gas-and-dust protoplanetary disk encircling the 20-million-year-old star Beta Pictoris. A proposed instrument would study these disks to learn more about the formation of planetary systems.

Goddard scientist Harvey Moseley has long wanted to build an instrument designed specifically for studying the processes that give birth to planetary systems. This fall, he and his team hope they'll finally get their chance.

NASA is expected to select this fall a third-generation instrument for the world's largest airborne observatory — the Stratospheric Observatory for Infrared Astronomy, or SOFIA. NASA and the German space agency, DLR, operate this modified Boeing 747-SP aircraft whose instruments have studied everything from star birth and death to black holes and complex molecules in space.

Now interested in hosting a next-generation instrument, NASA must choose between two contenders: Moseley's High-Resolution Mid-Infrared Spectrometer, or HIRMES, and the Jet Propulsion Laboratory's SOFIA Heterodyne Array for Spectroscopic Terahertz Astronomy, led by Principal Investigator Paul Goldsmith. Both instrument concepts are now being fine-tuned under Phase-A studies.

"I think we have a competitive science program. It provides a powerful new capability that doesn't exist in current or planned missions, including the European Space Agency's Herschel Space Observatory and NASA's James Webb Space Telescope," Moseley said. "We want SOFIA to play a role in resolving one of the most important questions in astrophysics: how do planetary systems form and evolve. This will provide us new insights into the origins of our own solar system."

Tried-and-True Technologies

Under his proposal, also involving Cornell University and a handful of other institutions, Goddard would manage, build, and integrate the instrument and Cornell would provide the Fabry-Perot Inter-

Continued on page 13

ferometer, which makes use of multiple reflections between two closely spaced surfaces. Part of the collected light is transmitted each time the light reaches the second surface, resulting in multiple beams that interfere with one another. Scientists analyze the interference pattern to learn more about the physical conditions they are studying.

In addition to managing the project, Goddard would provide HIRMES's all-important bolometer detectors, which, in essence, are very sensitive thermometers particularly effective at sensing infrared or heat radiation. They, too, are tried and true.

Invented by technologist Christine Jhabvala in part with Goddard R&D funding, the detectors initially debuted on the Goddard-IRAM Superconducting 2-Millimeter Observer, an instrument installed in a 30-meter telescope in Spain (*Goddard Tech Trends*, Spring 2008, Page 5). Since then, she and her team have applied the detectors' basic architecture to create a virtual family of detector arrays for different missions, including the balloon-borne Primordial Inflation Polarization Explorer (see related story, page 2).

Unique Spectral Range

With this combination of technology sensitive to the mid-infrared range of the spectrum — a wavelength band currently not covered by existing or planned infrared missions — HIRMES would examine with unprecedented resolution the structure and evolution of protoplanetary disks — the rotating circumstellar disks of dense gas and dust surrounding young, newly formed stars. These insights would significantly increase scientists' ability to model these systems as they evolve from homogeneous disks to fledgling planetary systems.

One of the questions HIRMES is expected to help answer is the origin and ultimate fate of water in the planet-forming regions of these disks, Moseley said.

"With new instrument capabilities, SOFIA will provide unique capabilities for the scientific community," he added. "It will address central scientific questions, such as those concerning planetary-system formation, in unique and powerful ways." ❖

CONTACT

Samuel.H.Moseley@nasa.gov or 301.286.2347

Two Sounding-Rocket Missions to Explore Nanoflares and Flying Atoms

Why is the sun's outermost layer 1,000 times hotter than the visible surface of the sun? What are the physical mechanisms that allow oxygen atoms in Earth's atmosphere to overcome gravity and race into Earth's protective magnetosphere and then out into space?

With two new sounding-rocket missions funded by NASA's Heliophysics Technology and Instrument Development for Science, or H-TIDeS program, Goddard scientists plan to learn more about these little-understood processes. Both potentially influence space weather and the magnetosphere's response to the onslaught of charged solar particles that race across the solar system and slam into Earth's magnetosphere, the magnetic bubble that shields it from hazardous solar storms.

Both missions trace their heritage to R&D-funded technologies and both have flown before. However, when they launch, possibly in 2018, they will employ different measurement techniques and conduct their investigations using improved, more sensitive instruments.

FOXSI-3

During its 15-minute flight from White Sands Missile Range in New Mexico, the Focusing Optics X-ray Solar Imager-3, or FOXSI-3, will search for tiny releases of energy in the active and quiet sun. Equipped with a hard X-ray imager/spectrometer, FOXSI will be able to directly look for faint events on the sun, including tiny energy releases commonly known as nanoflares. Principal Investigator Lindsay Glesener, of the University of Minnesota, is leading the effort.

"Hard X-rays are ideal probes for studying nanoflare release," said Goddard scientist Steven Christe, who is serving as the mission's co-investigator. "Since nanoflares theoretically convert magnetic energy into kinetic and thermal energies, they are an obvious candidate for supplying the needed energy to heat the million-degree corona. The theory is that these small events happen all the time. We need to look for their signatures."

Continued on page 16

Volume 12 • Issue 3 • Spring 2016

A Beautiful Mind: A Tribute to Richard G. Lyon (1958-2016)

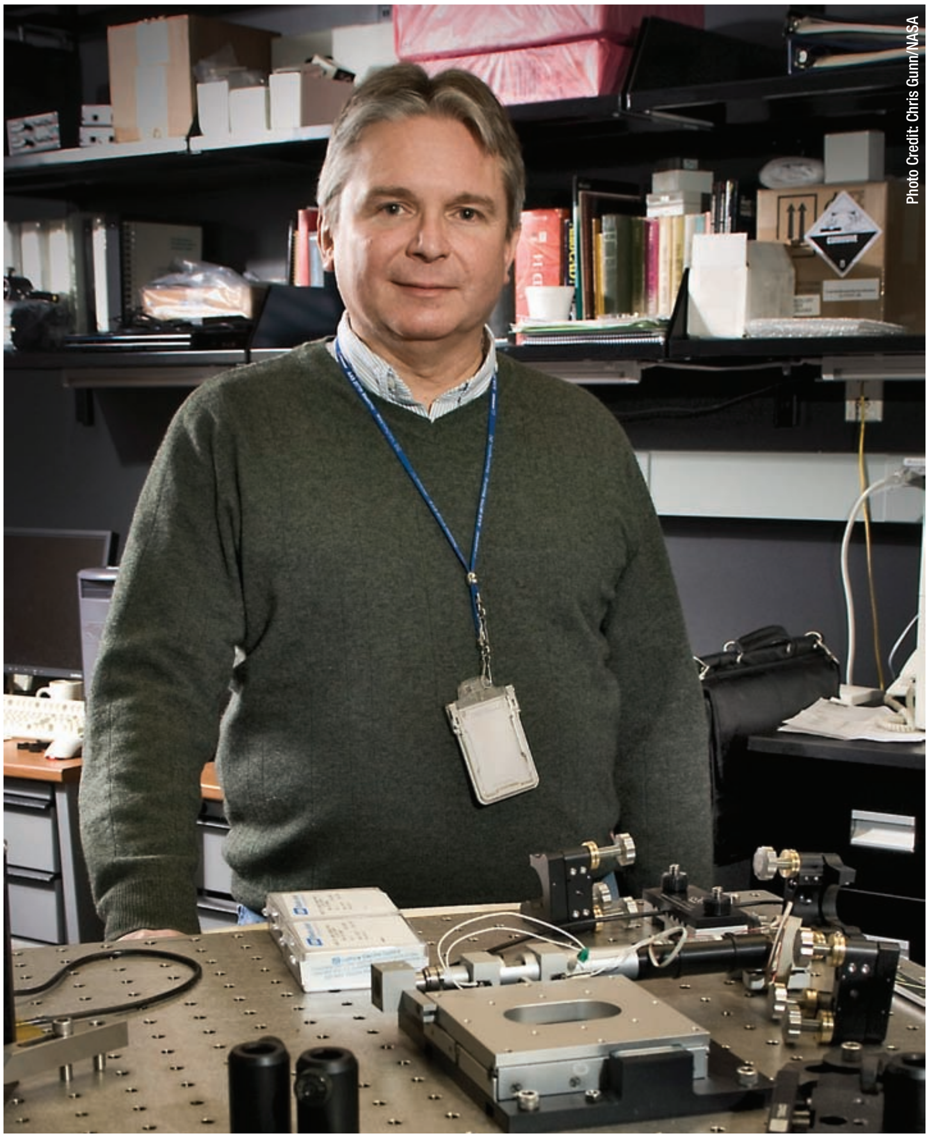


Photo Credit: Chris Gunn/NASA

Goddard scientist Mark Clampin always smiles to himself when he thinks of his long-time collaborator, Richard G. "Rick" Lyon, who passed away unexpectedly in late January due to complications from his late-2014 liver transplant.

"I think he was one of those rare optics experts who seemed to be able to think in Fourier space," said Clampin, who had worked with Lyon for many years developing a next-generation optics technology for detecting and characterizing Earth-like planets in other solar systems.

"I always smile to myself when I see a TV advertisement for LASIK surgery because I remember Rick telling me how he took the data for his eyes measured by the optician, and reprocessed it to get a better fit — just because he wanted to understand how it was done and could be improved."

A 'Brilliant Mathematician'

Universally described as a "brilliant mathematician" and even a "kind of living national treasure" by one of his colleagues, Lyon was born in Washington State. He came from a working family of watermen from the south side of Boston harbor and was the first person in the family to get a college degree, earning a B.S. in physics Magna Cum Laude from the University of Massachusetts and an M.S. in optics from the University of Rochester.

"We shared a love of workboats, harbors, seafood, and outdoor things," said Daniel Gezari, who had first met Lyon in 1995, later convincing him to join Goddard's Sciences and Exploration Directorate five years later as a civil servant. "Rick told me that he once drove 1,000 miles up the Alaskan Highway to someplace in the middle of the Yukon, parked the car, hiked alone perpendicular to the road for two days, and camped out there for two weeks. He had a great curiosity and love of nature."

Prior to joining NASA, and ultimately becoming a member of Goddard's Exoplanets and Stellar Astrophysics Laboratory, Lyon worked as an opti-

Continued on page 15

cal systems engineer for Perkin-Elmer Corp. (later known as Hughes Danbury Optical Systems) where he worked on the Hubble Space Telescope's Fine Guidance Sensors and then as a principal investigator for the phase-retrieval efforts to quantify aberrations in Hubble's primary mirror. He spent two years at the Air Force Research Laboratory before coming to Goddard in 1994 as a research scientist with the University of Maryland's Center of Excellence in Space Data and Information Systems.

Over his rich career, Lyon authored nearly 150 peer-reviewed journal articles, received NASA's Exceptional Service Medal in 2004, three NASA Group Achievement Awards, four Goddard Special Act Awards, and in 2012, the James Kerley Award, awarded by Goddard's Technology Transfer Program.

"Rick had an encyclopedic knowledge of modern physics. He was known as a world expert in optical physics," Gezari said. "If you asked him a complicated question he would proceed to give you an answer that would make a finished chapter in an advanced physics textbook."

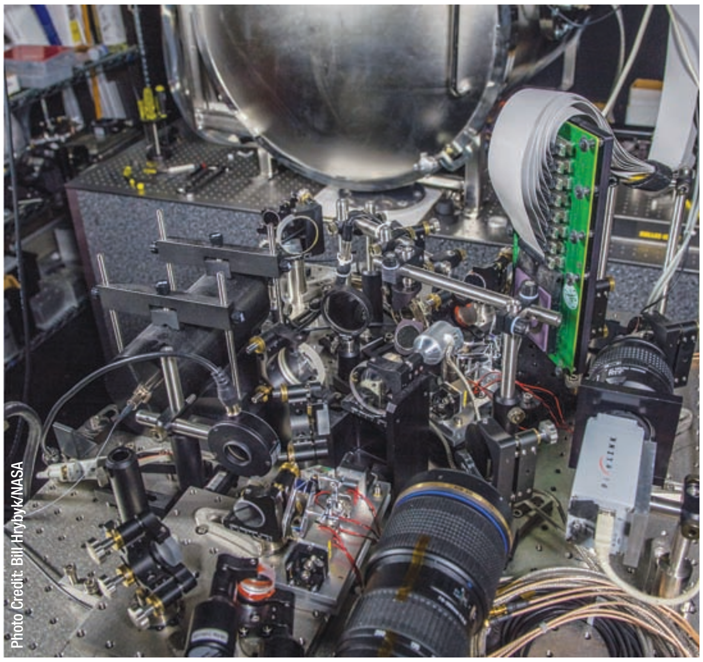


Photo Credit: Bill Hrybyk/NASA

Rick Lyon was the driving force behind the Visible Nulling Coronagraph, which could enable next-generation planet-finding missions.

Passion for Planet Finding

His consuming scientific passion, however, revolved around cosmology and more particularly directly imaging and characterizing planets in other solar systems. About six years ago, he began collaborating with Clampin to develop the Visible Nulling Coronagraph (VNC), a novel instrument that combines an interferometer with a coronagraph designed specifically for finding potential signatures of life in these far-flung worlds — a NASA first (*CuttingEdge*, Fall 2015, Page 4).

"Rick was a master of detail in optical design," said Karl Stapelfeldt, who formerly supervised Lyon before transferring recently to the Jet Propulsion Laboratory. "If you ever saw his VNC optical bench design, you'd understand that he had to be! Just when I had his VNC figured out, he invented a new version."

The most recently completed lab demonstration proved the VNC could achieve nearly billion-to-one contrast — to date, the deepest contrast ever achieved with a nulling coronagraph — but over a narrow band in the visible spectrum. Working with Brian Hicks, Pete Petrone, Matt Bolcar, and Udayan Mallik, Lyon conceived additional techniques to increase the VNC's sensitivity needed for detecting and characterizing Earth-like planets, all while recovering from his transplant surgery.

"He was the one guy I know who had the best chance of actually accomplishing this nearly impossible goal," Gezari added.

'Modest, Good-Hearted'

Despite his reputation as one of the world's foremost experts in optical physics, Lyon "was a modest, good-hearted guy, who did not think of himself as a celebrity or a superstar," Gezari continued. "He was very generous with his ideas and his knowledge. He did not have a selfish bone in his body."

One of the beneficiaries of his generosity was Hicks, who joined Lyon's team a couple years ago as a fellow with NASA's Postdoctoral Program. "It wasn't clear when Rick would be back to full health, but it was clear that he was going to do everything he could to keep elevating understanding," said Hicks. "I'll be doing my part to carry on his legacy, and many will be working to fully grasp the breadth of his work for some time to come. It was a privilege to have worked with Rick and to have had him as a mentor."

Lyon is survived by his wife, Karen, two sons, Keith Murray and Jack Dean, three siblings, four grandchildren, and many aunts, uncles, nieces, and nephews. ❖

Volume 12 • Issue 3 • Spring 2016

Sounding-Rocket Missions,

continued from page 13

Apart from their ability to potentially heat the corona, it's not known if nanoflares follow the same mechanisms that drive larger solar flares. Large flares accelerate charged particles that speed across the solar system, sometimes resulting in severe space-weather events. Whether the less-intense nanoflares are mini versions of this process or are just small heating events is a question scientists want to answer.

Although previous FOXSI missions have demonstrated the feasibility and potential for directly measuring the release of hard X-rays in the corona, the new version will carry upgraded optics and detectors that are expected to give scientists a better view of these highly energetic events.

"With FOXSI-3, we're trying to push the sensitivity as far as possible," Christe said.

VISIONS-2

Also slated to launch in 2018 is VISIONS-2, short for Visualizing Ion Outflow via Neutral Atom Sensing-2. It is specifically designed to investigate the outflow of oxygen ions from Earth's upper atmosphere and into the magnetosphere.

Unlike its predecessor — VISIONS-1 that observed the outflow at night from the polar auroral zones — this mission will observe the phenomenon during the day from Earth's magnetic cusps.

With this information, scientists hope to better understand the physics that influence Earth's magnetosphere. This is particularly important because most space assets, including communications satellites, reside there and are sensitive to severe space weather caused by the solar wind. Furthermore, the processes that heat and energize oxygen ions are universal in nature.

"These oxygen ions come and go in episodic bursts," said VISIONS-2 Principal Investigator Doug Rowland. "When they are present, which isn't all the time, they dramatically affect near-Earth space. Among other things, they can affect the rate

Photo Credit: Bill Hrybyk/NASA

Steven Christe is pictured here with a cadmium telluride detector made by the Rutherford Appleton Laboratory. It will be used on the FOXSI-3 mission. Goddard is developing its read-out electronics.

at which solar-wind energy is transferred to the magnetosphere, and the rate and details of how this stored energy is released to produce aurora," the display of lights typically seen at the poles.

In addition, a better understanding of the outflow could shed light on why Mars, which has a very weak magnetic field, is losing its atmosphere, while Venus, which has no magnetic field at all, remains enshrouded in a thick atmosphere.

VISIONS-2 will launch from Ny-Ålesund, Norway, carrying a payload of five different instruments. Goddard is providing the principal instrument, MILENA, which is short for Miniaturized Imager for Low-Energy Neutral Atoms. It traces its heritage to an instrument that flew on the U.S. Air Force-sponsored FASTSAT mission in 2011. Goddard also is providing the Fields and Thermal Plasma package, which consists of a double-probe electric field instrument. The Aerospace Corp. is providing the Rocket-borne Auroral Imager, the Energetic Ion Analyzer, and the Energetic Electron Analyzer.

"We don't have to fly through the ion outflow. What we'll be doing with VISIONS-2 is standing back and looking at the big picture," Rowland said. ❖

CONTACTS

Steven.D.Christe@nasa.gov or 301.286.7999
Douglas.E.Rowland@nasa.gov or 301.286.6659

Cutting edge Goddard's Emerging Technologies

CuttingEdge is published quarterly by the Office of the Chief Technologist at the Goddard Space Flight Center in Greenbelt, Maryland. The publication describes the emerging, potentially transformative technologies that Goddard is pursuing to help NASA achieve its mission. For more information about Goddard technology, visit the website listed below or contact Chief Technologist Peter Hughes, *Peter.M.Hughes@nasa.gov*. If you wish to be placed on the publication's distribution list, contact Editor Lori Keesey, *Lori.J.Keesey@nasa.gov.* NP-2016-4-410-GSFC